Heat Losses and Efficiencies of Otto Gas Engine.

A. H. S. Cantlin.
Sidney Hilborn.

Test of a One-Third Horse Power Otto Gas Engine

The following thesis is an account of a test on a one-third horse power Otto Gas Engine, manufactured by the Otto Gas Engine Company; 33rd and Walnut Streets, Philadelphia, to determine the heat distribution, efficiencies and indicated and brake horse powers.

The engine is part of the equipment of the mechanical laboratory of the University of Pennsylvania.

Two half hour – thirty minute – runs were made with the conditions as nearly identical as possible and they were taken together and worked up as one

test.

In the following description, the letters and numbers refer to the photograph of the engine and the apparatus used during the test on page 14a.

The engine consists of a vertical cylinder (16) 3 inches in diameter with a trunk piston packed with 5 metallic rings. The piston is connected to a cranked shaft (1) by the connecting rod (2) which has a 5 inch stroke. On one end of the shaft is the fly-wheel (10), two feet in diameter, and on the other a gear wheel, which gears into another wheel having twice the number of teeth. These gear wheels are enclosed in the cast iron case (y).

On the shaft of the second gear-wheel is an eccentric which operates the rod (22). This in turn operates the exhaust valve (u) and the governor (r). The governor controls the admission of the gas to the chamber (v) where it is stored before being admitted to the cylinder. The gas together with the air is admitted to the cylinder by the disc valve (w) which is raised by suction every fourth stroke of the piston. This valve has a number of holes in its seat which communicate with the chamber (v). Underneath, the valve is in communication with the air space between the bottom wall of the cylinder and the base of

the engine. When the valve is raised a mixture of air and gas is admitted which depends on the relative area through the holes and under the valve. The valve is held to its seat by a spring.

The governor consists of a round, threaded weight (r) on the end of a lever having a screw thread and a lock nut so the position of the weight can be changed. Its fulcrum is at (q) and the further end of the lever is held down by the spring (o). The pivot at (q) is part of the valve rod (22). Projecting downward from the fulcrum is a small rod (p) which is cast in one piece with the lever and which car-

nes a hook at its lower end. When the rod (p) hangs vertical the hook on the rod engages with a projection on the stem of the valve at (t) being held to its place by the spring (o). When the rod (22) is lifted the governor goes with it and the valve is raised admitting gas to the chamber (V). If the speed gets too fast the inertia of the weight overcomes the pull of the spring and causes the hook to miss the projection. The valve is not raised and no gas admitted. Consequently there is no explosion and the speed is reduced. The speed can be regulated by the position of the weight (r) on the

liver.
The gas is drawn from the main and passes through the meter (d), the equalizing bag (f) and the tap (s). The latter is supplied with a graduated disc and pointer.
The gas for the Bunsen burner enclosed in the cast iron cylinder (x) is drawn through the meter (e) and the regulating cock (23). This cylinder is lined with asbestos and an iron tube of small diameter, closed at the top, extends up the centre. The fire plays around this tube and keeps it red hot. The charge is compressed into this tube and exploded.
The air used is admitted

to the space below the cylinder wall through the pipe (6) and also through small holes in the bedplate.

The exhaust gases pass out through the exhaust valve (u) and the pipes (17) and (18) into the outside air.

A water jacket surrounds the cylinder, the water entering at the bottom and exhausting at the top through pipes at the back which cannot be seen in the picture. By means of pet cocks the water can be ex-hausted through the floor or discharged into collecting buckets.

The engine works in what is known as an 'Otto Cycle' and takes four strokes to complete a cycle. On the

first upward stroke the mixture is drawn into the cylinder; on the downward it is compressed and exploded as the engine reaches the dead point; on the third expansion takes place and on the fourth the exhaust.

The suction valve takes care of itself, while by means of the second gear wheel in the case (y) having twice the number of teeth on the first the other valves are opened every fourth stroke instead of every second.

Several precautions are necessary. All the valves must be kept clean and fit their seats truly or the engine will not run.

If the compression is not

good there will not be any explosion. The valve (w) must also be adjusted so that it is not raised too easily or too much. The supply of gas must also be regulated to suit the load, as for any given load there are certain limits in each direction for the ratio of air to gas and if these limits are passed there is no explosion and the engine stops. The ignition tube must also be kept hot. In starting the flywheel must be spun comparatively fast before an explosion will occur.

Instruments.

The following apparatus was used:—
The brake for determining the brake horsepower consisted of a strong cord (8) held in position by three wooden guides (9). On one end is hung a weight while to the other is attached the spring balance (7) which was held by a hook (19) in the floor.

The cards for the indicated horse power were taken with a Thomson Indicator (3) having a piston with an area of one quarter square inch and a larger one of one half a square inch. It was attached to the pipe (24) in connection with the lower

part of the cylinder. Communication was through a cock (2) on the pipe. The larger cylinder was used.
To get the required motion for the drum (3), a string (12) was fastened to a pin projecting from the hub of the fly wheel. This string was strong and was tied so it would not tighten and wrap up on the pin. It carried a loop at the lower end. Another string (25) was wound around the drum and had a hook on its free end. When the engine was running the string (12) was flung out by centrifugal force and could be caught in the hand. The hook of (25) was then placed in the loop of string (12) and the desired motion given to the drum (3).

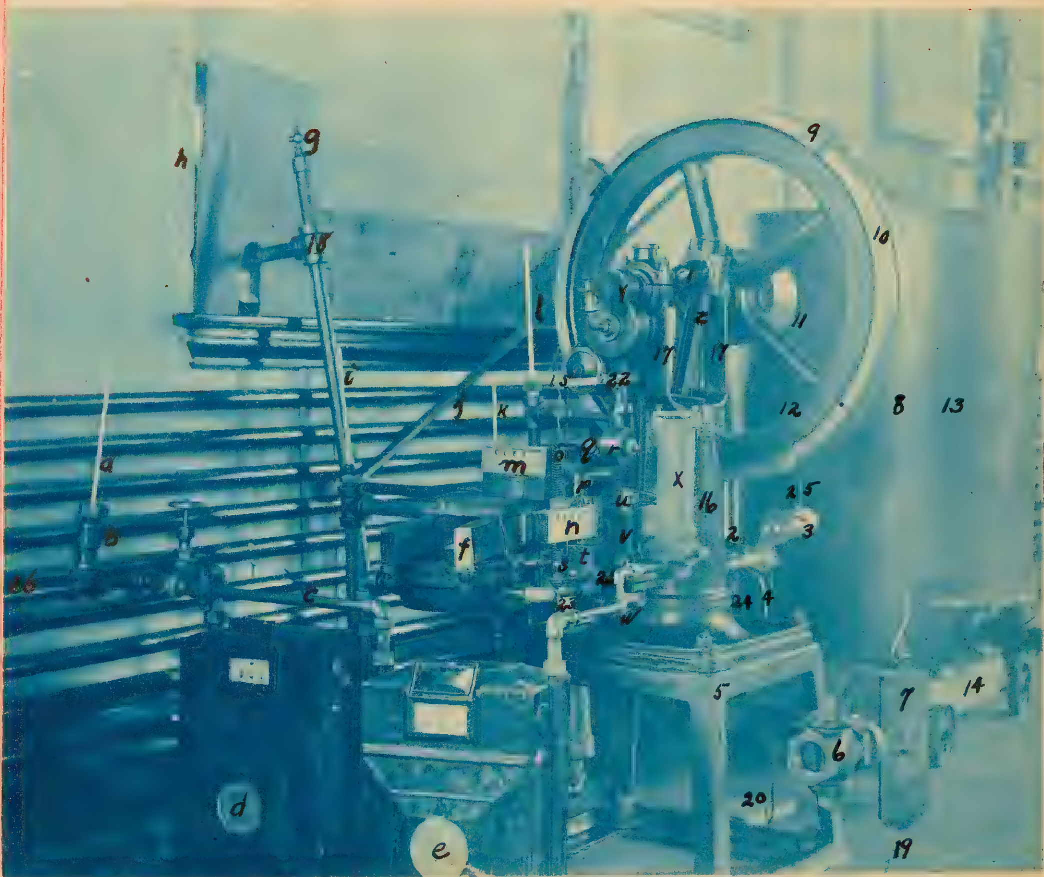
For the number of revolutions the counter (m) was fastened to a wooden frame and held firmly by being wedged under the piping. The iron rod (15) was clamped on the rod (22) and a wire at its outer end worked the counter. The counter was pulled back by a spring not shown in the picture. The number of revolutions is found by multiplying the reading of (m) by two since the rod (22) moves up and down once in every two revolutions.

For the number of explosions the counter (n) was attached to the valve (t) which supplies gas. When gas was admitted the valve was raised and this worked the counter. The gas for combustion was

measured by the meter (d) and gas for ignition by the meter (e).
The temperature of the incoming gas was measured by the thermometer (a) placed in a thermometer well (b) in the supply pipe.
The temperature of the exhaust gases was determined by the thermometer (i) also in a thermometer well.
A Bristol Recording Gauge - not shown in picture - in communication with (26) recorded the gas pressure in inches of water.
The temperature of the room was measured by the thermometer (h)
In order to keep the cylinder cool a certain amount of water, regulated by the outlet cock was allowed to flow through the jacket and was caught in buckets

and weighed, the buckets being weighed full and empty. The thermometers (K) and (L) placed in thermometer wells on the pipes measure the temperatures of the water at inflow and outflow respectively. The flow was regulated so the rise in temperature of the water was about constant during the test.

The clearance volume was determined by removing the piston and filling the cylinder up to a certain mark with water. The weight of this water was determined by taking the difference in weight of a bucket of water before the water to fill the cylinder was taken out, and after. The difference gives the weight and from this the



g
h
18
9
10
l
y
z
11
17
17
i
15
22
j
k
12
8
13
m
o
q
r
a
p
u
x
16
25
b
n
2
3
f
v
26
t
s
21
c
23
24
4
w
5
7
14
6
d
20
e
19

volume up to the mark was determined by finding the weight of a known volume of the water in a 200 c.c. bottle. By determining the volume from the mark to the bottom of the piston when at the bottom of its stroke and subtracting this from the first volume gives the clearance volume. The circumference of the fly wheel was determined directly by wrapping a tape measure around it.

Calibration of Instruments.

The gas meters were calibrated by connecting them in series to the top of a stand pipe filled with water. The water was then run out into a tank

volume up to the mark was determined by finding the weight of a known volume of the water in a 200 c.c. bottle. By determining the volume from the mark to the bottom of the piston when at the bottom of its stroke and subtracting this from the first volume gives the clearance volume. The circumference of the fly wheel was determined directly by wrapping a tape measure around it.

Calibration of Instruments.

The gas meters were calibrated by connecting them in series to the top of a stand pipe filled with water. The water was then run out into a tank

and weighed and the volume calculated. The readings of the meters before and after were taken and from these the readings of the meters for each cubic foot determined.

The indicator spring was calibrated by placing it on a ~~spipe~~ on a steam line and throttling the steam, readings being taken ascending and descending when the pressure was indicated by the steam gauge on the siphon on the steam line. The accuracy of the gauge was then tested with the Crosby Gauge Tester. The spring used was marked 100 lbs.

The spring balance was calibrated by hanging standard weights on it and was found correct.

As the 'Bristol Recording Gauge' read above the atmosphere, one leg of a manometer was opened to the atmosphere and the other connected to a glass Y tube by means of a rubber tube. One other leg of the Y was connected to the gauge and by blowing into the third leg, any pressure desired above the atmosphere could be measured on the manometer and compared to the gauge. The gauge was found correct. The humidity was found from the report of the U. S. Weather Bureau for Philadelphia.

Symbols.

H_b = barometric height in inches of mercury

P_b = barometric pressure in pounds per square foot. $P_b = H_b \times .4888 \times 144$

P_a = press. of air $= P_b - P'_{aw}$

P_{aw} = vapor press. in air, assuming air saturated.

h = % humidity.

P'_{aw} = vapor press. in air at given degree of saturation. $P'_{aw} = h P_{aw}$.

w_{aw} = wt. of moisture in 1 cu. ft. of saturated air

w'_{aw} = " " " " 1 " " " air, when humidity is h %. $w'_{aw} = h\, w_{aw}$.

T_a = absolute temp. of air.

b_a = per centage of air by weight in mixture of gas and air

b_g = per centage of gas by weight in mixture of gas and air. $\frac{b_a}{b_g}$ = air per lb. of gas.

M_a = total mass of air = $\frac{v_a}{v_g} M_g$

M_a' = mass of air for explosions

V_a = total vol. of air per hour = $\frac{M_a R_a T_a}{P_a}$

R_a = constant for air

V_a' = vol. of air per hour for explosions.

v_a = vol of air per minute = $\frac{V_a}{60}$

v_a' = vol. of air per min. for explosions = $\frac{V_a'}{60}$

T_{am} = temp. of vapor corresponding to pressure P_{am}.

m_a = mass of air per explosion = $\frac{v_a}{v_g} w_g$

H_g = press. in gas main in inches of water

P_g = press. in lbs. per sq. ft. corresponding to $H_g = \frac{62.425}{12} \times H_g$.

P_{gm} = press. of moisture in gas, assuming gas saturated at temp. of gas in main.

T_g = abs. temp. of gas in main.

w_{gm} = weight of moisture in cu. ft. of saturated gas.

v_g = vol. of gas per min. [illegible]

v_a' = vol. of gas per min. for ignition

P_g = press. of gas = $P_a + P_g - P_{gm}$

V_g = vol. of gas per hour w/o ignition.

v_g = vol. of gas per min. for ignition.

M_g = mass of gas per hour without ignition

R_g = constant for gas

N_r = revolutions per min.

N_a = no. of possible admissions per min. $= \frac{N_r}{2}$

N_e = no. of explosions per min.

T_e = abs. temp. of exhaust gas.

t_e = temp. F. of exhaust gas.

v_{ge} = vol. of gas per explosion $= \frac{v_g}{N_e}$

v_{gs} = specific vol. of gas $= \frac{R_g T_g}{P_g}$

w_{ge} = wt. of gas per explosion $= \frac{v_{ge}}{v_{gs}}$

w_{em} = wt. of moisture in exhaust per min.

P_e = press. of exhaust gases $= P - P_{em}$

P_{em} = press. of moisture in exhaust gases.

W_j = wt. of jacket water per min

t_1 = temp. of water entering

t_2 = temp. of water leaving

q = heat of liquid

r = heat of vaporization

c_v = spec. heat at constant volume

c_p = spec. heat at constant pressure

H = wt. of hydrogen in lb. of gas.

R_m = constant for vapor of water at low pressures

T_{em} = temp. corresponding to pressure P_{em}.

N_w = mass of jacket water per hour

L = length of stroke in feet

a = area of piston

P = mean effective pressure = $\frac{A}{L}$.

A = area of card

C_a = calorific value of one cu. ft. of gas

W_1 = wt. on scale side of rope brake

W_2 = wt. on opposite " " " "

$W_1 - W_2 = W$ = net pull on rope brake

H_c = heat of combustion per min.

H_a = heat brought in in air per min.

H_{am} = heat brought in in moist. of air per min.

H_g = heat brought in in gas per min.
H_m = heat brought in in moist. of air per min.
H_e = heat in exhaust gas per min.
H_{em} = heat in moist. of exhaust gas per min
H_j = heat carried off by jacket water per min
H_i = indicated work in heat units
H_r = heat lost by radiation.
e = mechanical efficiency
E' = type efficiency
E'' = actual efficiency

Formulae.

P & T = press. and temp. in cylinder

vol. of gas = $\dfrac{M_g R_g T}{P}$.

vol. of air for explosion = $\dfrac{M_a' R_a T}{P}$

vol. of air when no explosion = $\dfrac{(M_a - M_a') R_a T}{P}$

$$\frac{\dfrac{M_g R_g T}{P} + \dfrac{M_a' R_a T}{P}}{N_e} = \frac{\dfrac{(M_a - M_a') R_a T}{P}}{N_a - N_e}$$

$$M_a' = M_a \frac{N_e}{N_a} - M_g \cdot \frac{R_g}{R_a} \cdot \frac{N_a - N_e}{N_a} \qquad (1)$$

$$H_c = C_a \times w_{ge} \times N_e \qquad (2)$$

$$H_a = c_p \frac{M_a}{60} \times (T_a - T_{32}) \qquad (3)$$

$$H_{aw} = w_{aw} \left[q_{aw} + r_{aw} + .48 (T_a - T_{aw}) \right] N_a \qquad (4)$$

$$H_g = c_p \frac{M_g}{60} (T_g - T_{32}) \qquad (5)$$

$$H_{gm} = w_{gm} (q_{gm} + r_{gm}) \frac{V_g}{60} = w_{gm} \times \lambda_{gm} \times \frac{V_g}{60} \qquad (6)$$

$$H_e = c_p (T_e - T_{32}) \frac{M_g + M_a}{60} \qquad (7)$$

$$H_{em} = w_{em} \left[q_{em} + r_{em} + .48 (T_e - T_{em}) \right] \qquad (8)$$

$$H_j = \frac{M_w}{60} (q_1 - q_2) = M_j (q_1 - q_2) \qquad (9)$$

$$H_i = \frac{(I.H.P.) \times 33000}{778} \qquad (10)$$

$$H_r = (H_c + H_a + H_{aw} + H_g + H_{gm}) - (H_e + H_{em} + H_j + H_i) \qquad (11)$$

$$\frac{P_e V_e}{P_{em} V_e} = \frac{M_e R_e T_e}{W_{ew} R_m T_e} . \qquad P_o - P_{em} = P_e$$

$$P_e = \frac{M_e R_e}{W_{em} R_m} P_{em} = \frac{M_e R_e}{W_{em} R_m} (P_b - P_e)$$

$$\left(1 + \frac{M_e R_e}{W_{em} R_m}\right) P_e = \frac{M_e R_e}{W_{em} R_m} P_b$$

$$P_{em} = P_e \frac{W_{em} R_m}{M_e R_e} = P_b \frac{M_e R_e}{W_{em} R_m \left(1 + \frac{M_e R_e}{W_{em} R_m}\right)} \cdot \frac{W_{em} R_m}{M_e R_e}$$

$$P_{em} = \frac{P_b}{1 + \frac{M_e R_e}{W_{em} R_m}} \qquad (12)$$

$$W_{em} = 9H \frac{M_g}{60} + W_{am}' t_a + W_{gm} t_g \qquad (13)$$

$$I.H.P = \frac{P L a N_e}{33000} \qquad (14)$$

$$B.H.P = \frac{2 \pi r N r W}{33000} \qquad (15)$$

Vol. of gas per I. H. P. per hr. without ignition $= \frac{V_g}{I.H.P.}$ (16)

" " " " with " $= \frac{V_g + V_g}{I.H.P.}$ (17)

" " " " B. H. P. per hr. without " $= \frac{V_g}{B.H.P.}$ (18)

" " " " " with " $= \frac{V_g + V_g}{B.H.P.}$ (19)

$$e = \frac{B.H.P.}{I.H.P.} \qquad (20)$$

$$E' = 1 - \frac{T_3}{T_4}$$

v_3 = clearance vol + vol. stroke

v_4 = clearance vol

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{K-1} \qquad E' = 1 - \left(\frac{v_4}{v_3}\right)^{K-1} \qquad (21)$$

$$E'' = \frac{H_i}{H_c} \qquad (22)$$

$$E_2 = \frac{E''}{E'} \qquad (23)$$

Tables.

Table 1.

Counters.

Time.	Rev.	Explosion.
12.37	4919	7822
12.43	5920	8572
12.50	7280	9700
12.56	8430	10720
1.01	9410	[illegible]
1.07	10650	[illegible]
2.25	9150	6090
2.31	9915	6845
2.56	[illegible]	7475
2.41	11205	[illegible]
2.46	11800	[illegible]
2.51	12480	[illegible]
2.56	13130	[illegible]

Table 2.

Temperatures.

Time.	Gas. Inlet	Gas. Exhaust	Jacket Water. Inlet	Jacket Water. Exhaust	Air.
12.37	84	363	80	110	84
12.43	84	387	78	105.5	85
12.50	84	432	79	109.	85
12.56	84	461	77.5	98	85
1.01	84	474	78	105.5	85
1.07	84	479	79	107	85
2.25	86	404	82	108.5	87
2.31	86	419	83.5	113.	87
2.36	86	420	82	106.5	[illegible]
2.41	86	428	77.5	105.5	[illegible]
2.46	86	428	81	104.	[illegible]
2.51	86	429	80	106.	[illegible]
2.56	86	426	83.5	104.5	[illegible]

Table 3.

Jacket Water.

Time.	No. Bucket	Empty. lbs.	Empty. oz.	Full. lbs.	Full. oz.
12.37.00	1	2	14 1/4	22	15 1/2
12.41.10	2	2	11 9/16	20	15 1/2
12.47.00	1	2	14 1/2	21	4
12.51.10	2	2	11 1/2	23	13 1/4
12.54.10	1	2	14 1/2	21	11 1/2
12.59.30	2	2	11 1/2	21	00 3/4
1.04.30	1	2	14	12	11
1.07.00					
2.25.00	1	2	14 3/4	20	2 1/4
2.29.45	2	2	11 3/8	21	14 1/2
2.35.10	1	2	14 1/2	22	15 1/2
2.38.40	2	2	11 1/4	22	13 3/4
2.42.35	1	2	14 3/8	22	8 1/4
2.47.30	2	2	11 5/8	24	2
2.52.00	1	2	14 1/2	22	5 1/2
2.56.10					

Table 4.

Meters – Gas.

Time	Cylinder	Time.	Ignition.
12.26.35	0	12.37.45	0
12.31.50	2	12.48.30	1
12.36.45	4	1.00.00	2
12.41.55	6	1.06.15	2.5
12.47.25	8	—	—
12.53.00	10	—	—
12.57.50	12	—	—
1.00.05	13	—	—
2.26.35	0	2.18.30	0
2.32.00	2	2.29.30	1
2.37.10	4	2.52.30	3.
2.42.25	6	—	—
2.47.30	8	—	—
2.52.30	10	—	—
2.57.20	12	—	—

Table 5.

Brake.

Time.	lbs.	oz.
12.37	2	15
12.43.	3	2
12.50	3	4
12.56.	3	8
1.07	3	10
1.07.	3	10
2.25	3	8
2.31.	3	8
2.36.	3	12
2.41.	3	12
2.56.	3	12
2.51.	4	0
2.56.	4	0

Wt of poise – 14½ oz.

" " balance – 2 lbs. 3¼ oz.

Additional Readings.

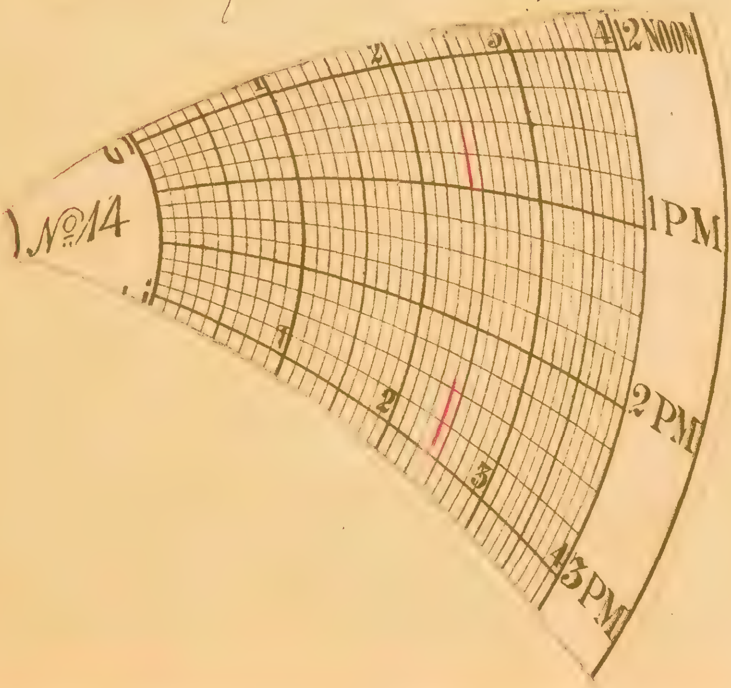
Calibration of Meters.

Cylinder meter	1 cu. ft	1.177 cu. ft.
Syphon meter	1 cu. ft.	[illegible] cu. ft.

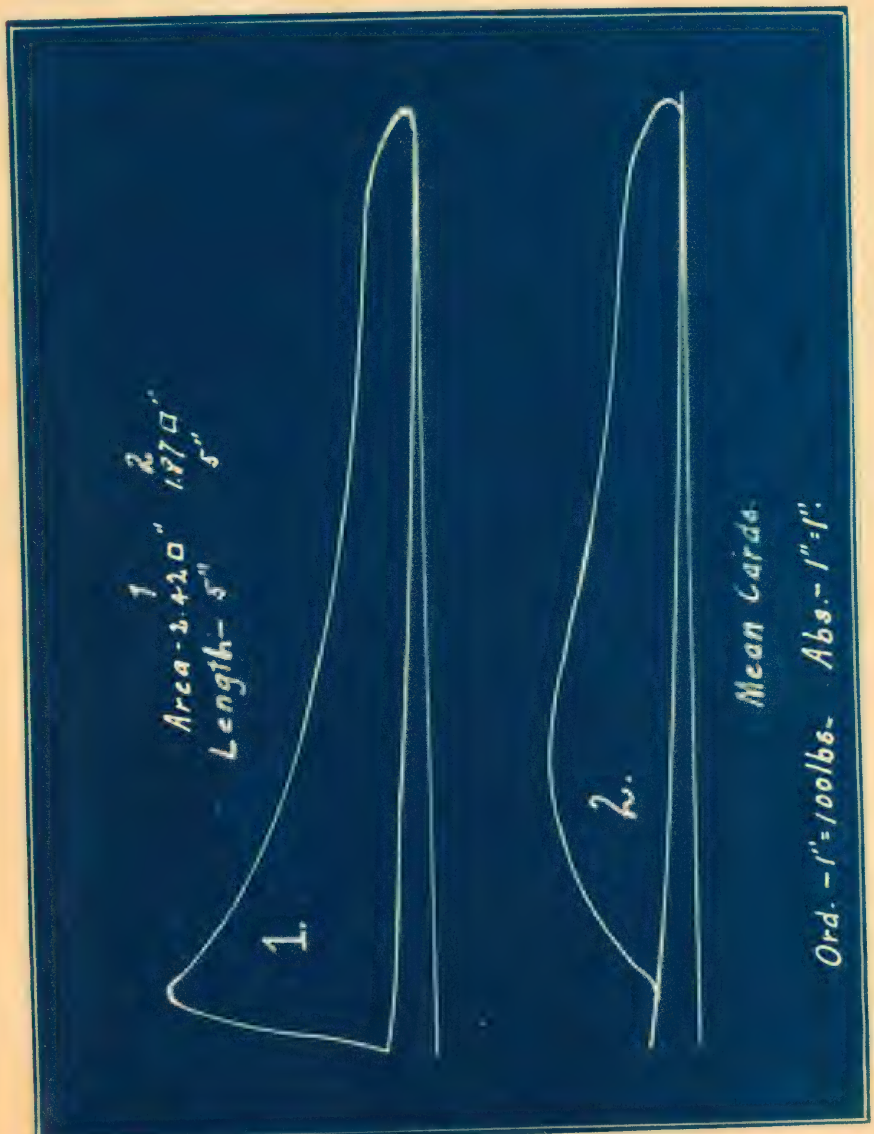
U. S. WEATHER BUREAU, Philadelphia,
Monday, May 1, 1899.

Time	Barometer	Temperature	Relative Humidity	Wind. Direction	Wind. Velocity	Rainfall	State of Weather
8 A. M.	30.11	61	83	S. W.	12	0	Pt. Cl'dy
8 P. M.	30.00	74	59	S. W.	12	0	Pt. Cl'dy

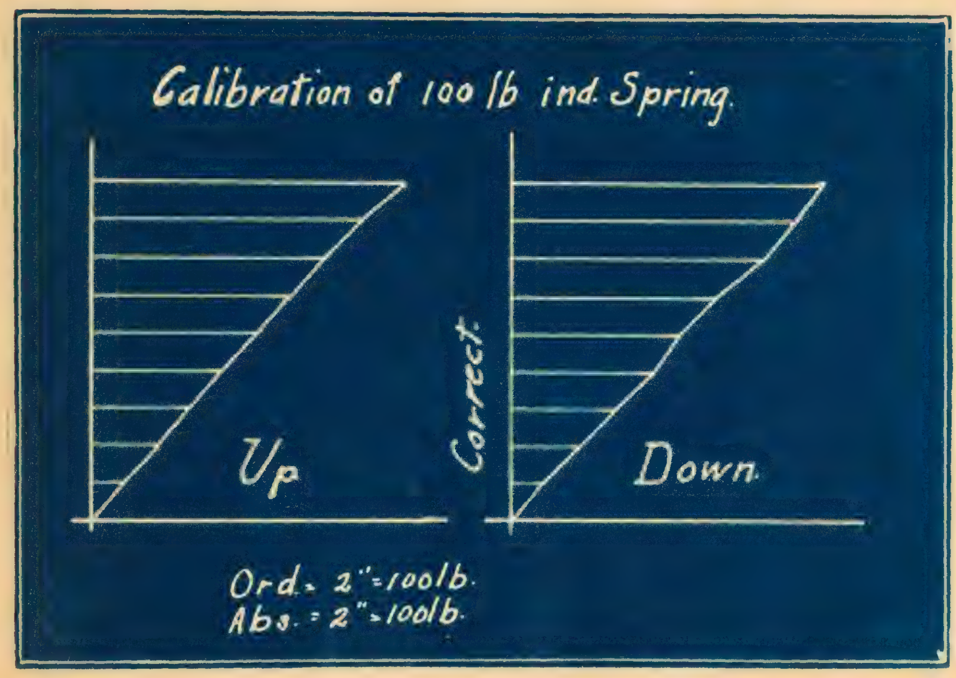
Bristol Recording Gauge.
Card from Gas Main.



Mean Cards.



Indicator Spring Calibration Curve.



The Mean Cards above were constructed in the following manner:- Each card had its base divided into 10 parts. In order for these parts to be equal parts of the stroke, the angularity

of the connecting rod and string was allowed for by connecting up the indicator as in use and moving the piston equal parts of its stroke and a mark made with the indicator pencil on a paper on the drum and the cards correspondingly marked. The distances on the mean card were made equal and the corresponding pressures corrected according to the spring calibration.

Test.

In starting the test the engine was run up to speed with the required load and run for about a quarter of an hour under the conditions of the test until the temperatures become steady. The test was started by a simultaneous reading of the revolution and explosion counters. Then the temperatures of the room, inlet and exhaust gases, and inlet and discharge jacket water and the reading of the brake were made in order and a card taken from the indicator. This series of operations was repeated every five minutes. One min-

ute before the beginning of the test a bucket was placed under the jacket water outlet and as the buckets filled they were weighed and emptied. Two buckets were used and one minute before the end of the test the last bucket was removed and weighed, the water flowing at practically the same rate all the way through. The test was ended by taking a simultaneous reading of the revolution and explosion counters after which the temperatures and brake were read to fill out the readings, before the engine was stopped.
At intervals during the

test samples of the fresh and exhaust gases were taken and were subsequently analyzed in a set of Hempel's apparatus.
The exhaust gas was drawn from the pipe (18) by a rubber tube attached above the cock (9) and the gas collected over water in a sealed bottle. By opening the cock (9) the gas was drawn out.
A similar arrangement on the gas main (26), not shown in the picture, allowed the fresh gas to be collected.
The time the two cubic foot hand of the combustion gas meter passed a mark just before the test, was noted and every time it again passed the mark was noted until after the end of the

test. From this the gas used during the test was computed.
In a similar manner every time the ignition meter hand passed a one cubic foot mark, the time was noted.

Results.

Analyses of Gases.

Philadelphia Illuminating Gas.

	% Vol.			% Wt.
CO_2 —	2.4	× 22 =	52.7 —	6.70
CO —	16.5	× 14 =	230.5 —	29.30
C —	.6	× [illegible] =	7.6 —	1.22
C_2H_4 —	5.2	× 14 =	72.8 —	9.89
H	31.9	× 1 =	31.9	4.05
CH_4	37.1	× 8 =	296.5 —	37.65
N —	6.3	× 14 =	88.1 —	11.19
	100.0		782.1	100.0

Exhaust Gas

	% Vol.			% Wt.
CO —	0	× 14 =	0 —	0
CO_2 —	7.05	× 22 =	[illegible].1	0.56
O —	5.95	× 16 =	95.2 —	6.49
N —	87.00	× 14 =	1218.0 —	82.95
	100.0		1464.3	100.0

Properties of Gases

Philadelphia Illuminating Gas

	C_p	C_v
CO_2 —	$6.7 \times .217 = 1.453$	$6.7 \times .1535 = 1.03$
CO —	$29.3 \times .2479 = 7.260$	$29.3 \times .175[illegible]$ 5.15
O —	$1.22 \times .2175 = .265$	$1.22 \times .155 = .189$
H —	$4.05 \times 3.409 = 13.800$	$4.05 \times 2.412 = 9.750$
CH_4 —	$37.65 \times .593 = 22.350$	$37.65 \times .467 = 17.$[illegible]
C_2H_4 —	$9.89 \times .404 = 3.990$	$9.89 \times .332$ 3.28
N —	$11.19 \times .2438 = 2.730$	$11.19 \times .173 = 1.935$
	51.848	38.864

R_g (1 lb gas) $.51848 - .38864 = .12984$ B.T.U.

$= 101.2$ foot pounds.

Exhaust Gas

	C_p	C_v
CO_2 -	$10.56 \times .217 = 2.285$	$10.56 \times .1535 = 1.621$
O	$6.49 \times .2175 = 1.410$	$6.49 \times .155 = 1.006$
N	$82.95 \times .2438 = 20.250$	$82.95 \times .173 = 14.350$
	23.945	16.977

R_e (per lb of gas) $= .23945 - .16977 = .06968$ B.T.U.
$= 54.211$ foot-lbs.

Gas for ignition in cubic ft. per hour. Found by dividing the number of cu. ft. by the time in minutes taken to pass through, multiply by 60 and divide by calibration of the meter.

$$\text{Gas ignition} = \frac{5.5 \times 60}{62.5 \times 1.001} = 5.28 \text{ cu ft}$$

Same for gas for combustion

Gas $\dfrac{25 \times 60}{64.15 \times 1.177} = 19.8$ cu. ft. per hour

Calorific Value of Gas.

CO — $4300 \times .293 = 1259.$

CH_4 — $23500 \times .3765 = 8847.75$

C_2H_4 — $21400 \times .0989 = 2116.46$

H — $52500 \times .0405 = \underline{2126.25}$

Value per lb. gas = 14349.46 B.T.U.

Ratio of air to gas by weight.

Find the ratio of gas to carbon in the fresh gas and multiply by the per cent of carbon in exhaust gas. The result is the per cent of gas supplied to form the exhaust gas. The remainder of exhaust gas is air.

Gas in combination of gas and air.

Fresh Gas % C

C in CO_2 = x 6.7 - 1.83

C in CO - 2 x 29.3 12.57

C in C_2H_4 - $\frac{24}{28}$ x 9.89 8.48

C in CH_4 = $\frac{12}{16}$ x 37.65 28.25

Total C 51.13

Exhaust Gas % C

C in CO_2 - $\frac{12}{44}$ x 10.56 2.88 Total C

% Gas = $\frac{100}{51.13}$ x 2.88 = 5.64%

% air supplied 100 - 5.64 = 94.36

∴ Lbs of air per lb of gas = $\frac{94.36}{5.64}$

= 16.73 lbs

Specific Volume of gas in main = $\frac{RT}{P}$

P = bar. pres. + gauge pres - vapor pres.

Bar. pres. = $30.06 \times .4888 = 14.69$ lbs per sq. in.

Gauge pres. = $2.4 \times .0361 = .0866$ lbs per sq. in.

Assume gas is saturated.

Vapor pressure saturated at 85° F.

$= .591$ lbs per sq. in

$\therefore P = 14.69 + .0866 - .591 = 14.1856$ lbs per sq.

$$\therefore \text{Specific Vol} = \frac{101.2 \times (460.7 + 85)}{14.1856 \times 144}$$

$= 26.98$ cu ft

$$\text{Vol. gas per explosion} = \frac{\text{cu. ft. per hour}}{60 \times \text{expo. per min.}}$$

$$= \frac{19.8}{60 \times 141.1} = 00233876 \text{ cu ft}$$

Weight of gas per explosion

$$= \frac{\text{vol. per explosion}}{\text{specific volume}} = \frac{.00233876}{26.98}$$

$= .000086685$ lbs

Wt. of air per explosion = wt of gas per explo. × ratio air to gas = 16.75 × .000086685

= .0014597 lbs.

Total air per hour = .0014597 × 141.1 × 60

= 12.2915 lbs.

Volume of air per hour $= \frac{MRT}{P}$

P = Bar. Pres − vapor pressure

T = 86.23 Saturation = 71%

Bar pressure = 14.72 lbs per sq. in.

Pressure assuming saturation = .61 lbs

∴ vapor pressure = .61 × .71 = .43 lbs per sq. in

∴ P = 14.72 − .43 = 14.29

$$\therefore V = \frac{1\text{[illegible]}9 \times \text{[illegible]}37 \times (86.23 + \text{[illegible]}60.7)}{14.21 \times 144}$$

= 174.375 cu. ft. per hour

Volume of air used only when explosions. When there are explosions only air is

drawn in. Assuming the pressure on gas and air is same and that cylinder volume is sum of the volumes of the gas and air we get formula (1). &

$$M_a' = 12.29 \times \frac{141.1}{\frac{318.4}{2}} - \frac{18.1}{\frac{318.4}{2}} \times \frac{101.2 \times .00086685 \times 141.1 \times 60}{53.37}$$

$$= 10.893 - .15821 = 10.735 \text{ lbs per hr}$$

$\therefore$ Lbs per explosion $= \frac{10.735}{60 \times 141.1} = .001268$ lbs

Volume of air for explosions per hour

$= \text{total vol of air} \times \frac{\text{wt. air for explosions}}{\text{wt of total air}}$

$= 174.375 \times \frac{10.735}{12.29} = 152.31$ cu ft.

Volume per explosion $= \frac{152.31}{60 \times 141.1}$

$= .017991$ cu. ft.

Indicated H.P. — See formula (14).

P was found from the cards. Since there were 5 cards like the first and 7 like the second, they were multiplied by these numbers respectively and divided by the sum to find mean and and then by the length for M.E.P.

$$\therefore \quad I.H.P. = \frac{41.98 \times 5 \times .7854 \times 9 \times 141.1}{12 \times 33000}$$

$$= .527$$

since $M.E.P. = \dfrac{5 \times 24.2 + 7 \times 1.87}{12 \times 5}$, scale $= 41.98$

Brake Horse Power — See formula (15)

W is found by adding the weight of the spring balance to its indicated pull and subtracting the weight on the other end

$$B.H.P. = \frac{318.4 \times 6.28 \times 4.87}{33000} = .295$$

Gas per I.H.P. without ignition per hour $= \frac{19.8}{.527} = 37.57$ cu ft

Same with ignition gas $= \frac{19.8 + 5.28}{.527}$

$= 47.59$ cu. ft.

Gas per B.H.P. per hour without ignition

$= \frac{19.8}{.295} = 67.11$ cu ft.

Same with ignition gas $= \frac{25.08}{.295}$

$= 85.02$ cu. ft.

Clearance.

wt. of water in cylinder = 2.919 lbs.

wt. of 15.23 cu. in. of water = .547 lbs.

Vol. of water $= \frac{2.919 \times 15.23}{.547 \times 1728} = .047$ cu. ft.

Vol. of displacement $= \frac{3^2 \times .7854 \times 8\frac{1}{4}}{1728} = .0362$ cu. ft.

Mean v. = .047 ÷ 4 = .0118 cu. ft.

Efficiencies.

$e = \frac{.295}{.527} = .56$ from formula (20)

$E'' = \frac{.527 \times 33000}{778 \times 1.2 + 39 \times 141.1} = .1274$ formula (21)

$$E' = \frac{c_v(T - t_c) - c_v(T' - t)}{c_v(T - t_c)}$$

Since both curves are adiabatic, and pass through the same volume change

$$\frac{T'}{T} = \frac{t}{t_c}.$$

From this we have $\frac{T' - t}{T - t_c} = \frac{T'}{T} = \frac{t}{t_c}$. Then

$$E' = 1 - \frac{T'}{T} = 1 - \frac{t}{t_c}.$$

On page 24, formula 21, E' is expressed in terms of the volumes by replacing

the temperatures by their equivalents in volumes.

Volume of piston displacement $= \frac{3^2 \times .7854 \times 5}{1728}$

$= .0204$ cu. ft. $= v_4$

Total volume $= .0204 + .0108 = .0312 = v_3$

$$E' = 1 - \left(\frac{.0108}{.0312}\right)^{.41} = 1. - .647 = .353$$

$$E_2 = \frac{.1274}{.353} = .361 \quad \text{formula (23).}$$

c. Heat Entering Engine.

$H_c = 14349.46 \times .000086685 \times 141.1 = 175.51$ B.T.U.

per min formula (2)

$H_a = .2375 \times 16.75 \times .000086685 \times 141.1 \times (86.23 - 32)$

$= 2.6387$ B.T.U. per min. formula (3).

c. Moisture in air.

wt. of vapor in 1 cu. ft. of saturated air at $86.23°$

$F = = w_{aw} = .001914$ lbs.

wt. when humidity $= 71\%$ or $h = h w_{am} = w_{aw}$

$= .71 \times .001914 = .001359$ lbs.

Vapor press. at 86.23 when saturated = P_{am} = .615 lbs. □"

P'_{am} = press. at 71% humidity = .71 × .615 = .437 lbs □"

T_{am} = corresponding temp. to P'_{am} = 75°.63.

When the air is not saturated the vapor is superheated, and therefore the heat brought in in the moisture is equal to the heat of the liquid, the heat of vaporization and the heat of superheat. By formula (4)

$$H_{am} = .001359[43.75 + 1061.3 + .48(86.23 - 75.65)] \times \frac{174.375}{60} = 4.3844 \text{ B.T.U. per min}$$

$$H_g = .5185 \times .0000\,86685 \times 141.1 \times (85 - 32) = .33612 \text{ B.T.U. per min.}$$ formula (5)

Since the fresh gas is saturated with moisture, the heat brought in in the moisture is equal to the heat of the liquid and the heat of vaporization. By formula (6)

$$H_{gm} = .001813 \times 1107.9 \times \frac{19.8}{60} = .66284$$

.001813 lb. is the mass of moisture in 1 cu. ft. of gas at the temperature of the gas 85°F. when saturated

Heat Saving Engine.

The indicated work is here expressed in B.T.U. by formula (10)

$$H_i = \frac{.527 \times 33000}{778} = 22.353 \text{ B.T.U. per min}$$

The heat saving in the jacket water as expressed by formula (9) is the mass of water multiplied by the difference between the heat of the liquid at entrance and exit.

$$H_j = \frac{261.75}{60} \times 26.1 = 113.861 \text{ B.T.U.}$$

$$H_e = .23945 \times (427.4 - 32)(.20486 + .01223)$$

$$= 20.554 \text{ B.T.U. By formula (7)}$$

Moisture in exhaust gas.

H in 1 lb. fresh gas (free) = .04051 lb.

H in $C_2H_4 = \frac{4}{28} \times .0989$ = .0141 "

H in $CH_4 = \frac{4}{16} \times .3765$ = .0941 "

total H in 1 lb. of gas = .1487 "

wt. of H_2O formed from H = 9 x .1487 = 1.3383 lb

amt. of gas per min. = .01223 lbs.

H_2O formed per min = .01223 x 1.3383 =

.01637 lbs.

H_2O in air per min = .00395 "

" " gas " " = .00060 "

Total moisture = .02092 "

By formula (12) we obtain pressure of vapor, and from tables the corresponding temperature may be found.

$$P_m = \frac{14.72}{1 + \frac{.21709 \times 54.211}{.02092 \times 85.732}} = 1.95 \text{ lbs. } \square''$$

Corresponding temp. = [illegible]

From a similar formula to that used in finding heat brought in in moisture of air we have by formula (8)

$$h_{ew} = .02092[93.5 + 1026.7 + .48(427.4 - 125.4)]$$
$$= 26.466 \text{ B.T.U.}$$

Heat Balance.

Entering

	per min.	per. 100 B.T.U.
Combustion	175.51000	95.629
Air	2.63870	1.438
Moist. of Air	4.38440	2.389
Gas	.33612	.183
Moist. of Gas	.66284	.361
	183.53206	100.000

Leaving.

	per min	per ct. B.T.U.
I.H.P.	22.353	12.177
Jacket water	113.861	62.035
Ex. Gas.	20.554	11.200
Moisture in Ex. Gas	26.466	14.426
Radiation	.299	.163
	183.532	100.000

The heat lost by radiation is the amount of heat by which the heat leaving the engine is less than the heat entering.

$H_r = 183.532 - 183.233 = .299$ B.T.U.

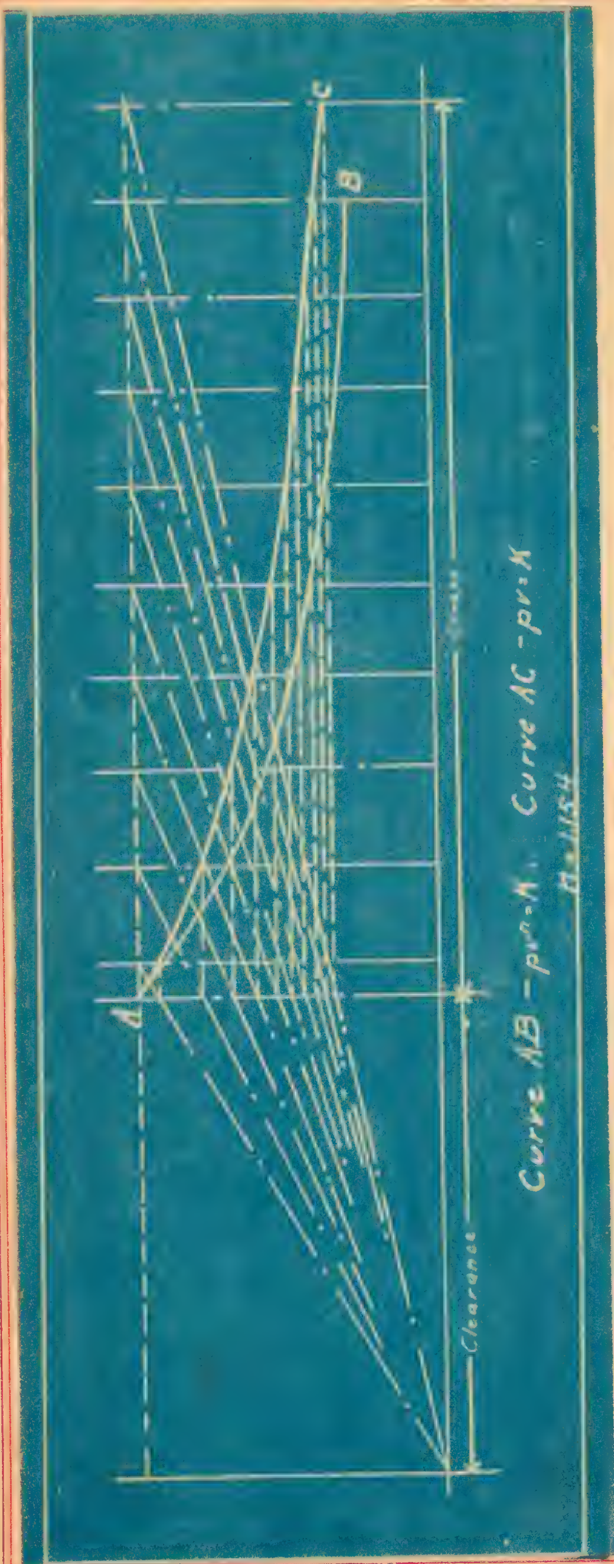
Result of Test

May 1 18[illegible]

1.	Duration of test in minutes	60
2.	Diameter of cylinder in inches	3
3.	Length of stroke in inches	5
4.	Circumference of fly-wheel in feet	6.28
5.	Atmospheric pressure (barometer) inches	30.56
6.	" " lbs. per □ in.	14.69
7.	Pressure in gas main in inches of water	2.4
8.	Max. pressure in cylinder above atmosphere in lbs. per □ in.	114
9.	Mean effective pressure in lb per □ in.	41.98
10.	Mean temperature of air	86.23
11.	" " " fresh gas	85
12	" " " exhaust gas	407.4
13.	" " " entering jacket water	80.2
14	" " "leaving " "	108.4
15.	" effective pull on brake in lbs.	4.87
16	Revolutions per minute	318.4
17.	Explosions per minute	141.1

18.	Indicated horse power	.527
19.	Brake horse power	.295
20.	Gas per hour without ignition (cu. ft.)	19.8
21.	" " " for " (" ")	5.28
22.	Total gas per hour (cu. ft.)	25.08
23.	Wt. of gas per explosion (lbs.)	.00086[illegible]
24.	Vol. of gas per explosion (cu. ft.)	.0023376
24a.	Calorific value of gas per lb. in B.T.U.	14[illegible]
25.	" " " " per explosion "	1.2439
26.	Gas per I.H.P. per hr. without ignition (cu. ft.)	37.57
27.	" " " " " with " (" ")	47.59
28.	" " B.H.P. " " without " (" ")	67.11
29.	" " " " " with " (" ")	85.02
30.	lbs. of air per lb. of gas.	16.75
31.	wt. of air per explosion (lbs)	.00145197
32.	vol. of air per explosion (cu. ft.)	.017991
33.	vol. of air per hr. for explosion (cu. ft.)	152.31
34.	Total air per hour (cu. ft.)	174.375
35.	Total air per hour (lbs.)	12.2915
36.	[illegible] efficiency	.[illegible]

37. Actual efficiency	.1274
38. Ratio of actual to type	.361
39. Mechanical efficiency	.86



Equation of Expansion Curve

The general equation of the curve is

$pv^n = K$

by the method of least squares the value of the coefficient n may be obtained. The equation $pv^n = K$ is expressed in the following form —

$\log p + n \log v = \log K$.

A [illegible] of

equi-distant points was selected on the abscissa and the pressure and volume for each point measured on the curve. The logarithms of these values were substituted in the equation given above.

Then the coefficient of n was taken and used as a multiplier in each equation. Thus a second set of equations were obtained. Each set were added and two equations containing two unknowns — K and n — were obtained. These were solved for n.

Then the curve $pv = K$ was drawn. According to the value of n the expansion curve should fall above or below the curve $pv = K$. If n is less

than one the expansion curve should fall above $pv = K$. If greater than one the curve $pv^n = K$ should fall below the curve $pv = K$.

Solving for n as described above we obtained a value

$n = 1.154$.

[illegible]